## Detection of *p*-process <sup>146</sup>Sm nuclide by accelerator mass spectrometry

N. Kinoshita<sup>1</sup>, T. Hashimoto<sup>1</sup>, T. Nakanishi<sup>1</sup>, A. Yokoyama<sup>1</sup>, H. Amakawa<sup>2</sup>,
T. Mitsugashira<sup>3</sup>, T. Ohtsuki<sup>4</sup>, N. Takahashi<sup>5</sup>, J.P. Greene<sup>6</sup>, D.J. Henderson<sup>6</sup>,
C.L. Jiang<sup>6</sup>, H.Y. Lee<sup>6</sup>, M. Notani<sup>6</sup>, R.C. Pardo<sup>6</sup>, N. Patel<sup>6</sup>, K.E. Rehm<sup>6</sup>,
R. Scott<sup>6</sup>, R. Vondrasek<sup>6</sup>, L. Jisonna<sup>7</sup>, P. Collon<sup>8</sup>, D. Robertson<sup>8</sup>,
C. Schmitt<sup>8</sup>, X.D. Tang<sup>8</sup>, Y. Kashiv<sup>9</sup> and M. Paul<sup>9</sup>

<sup>1</sup>Graduate School of Natural Science and Technology, Kanazawa University, Ishikawa 9201192, Japan
<sup>2</sup>Ocean Research Institute, The University of Tokyo, Tokyo 164-8639, Japan
<sup>3</sup>Institute for Material Research, Tohoku University, Ibaraki 311-1313, Japan
<sup>4</sup>Graduate School of Science, Tohoku University, Miyagi 982-0826, Japan
<sup>5</sup>Graduate School of Science, Osaka University, Osaka 560-0043, Japan
<sup>6</sup>Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA
<sup>7</sup>Department of Physics and Astronomy, Northwestern University, Evanston, Illinois 60208-3112, USA
<sup>8</sup>Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556-5670, USA
<sup>9</sup>Racah Institute of Physics, Hebrew University, Jerusalem 91904, Israel

Tb146	Tb147	Tb148	Tb149	Tb150	Tb151	Tb152	Tb153	Tb154	Tb155	Tb156	Tb157	Tb158
8 s 1+	(1/2+)	00 m 2-	4.118 h 1/2+	(2-)	17.009 h 1/2(+)	17.5 h 2-	2.34 d 5/2+	21.5 h	5.32 d 3/2+	5.35 d 3-	71 y 3/2+	180 y 3-
EC *	EC *	EC *	ΕC,α	EC,α *	ΕC,α	ΈC,α *	EC	ЕС,β-	EC	EC,β-	EC	ЕС,β-
Gd145	Gd146	Gd147	Gd148	Gd149	Gd150	Gd151	Gd152	Gd153	Gd154	Gd155	Gd156	Gd157
1/2+	48.27 a 0+	38.00 h 7/2-	0+	9.28 d 7/2-	0+	7/2-	1.08E.14 y 0+	241.0 d 3/2-	0+	3/2-	0+	3/2-
EC T	EC	EC	α	EC,α	α	EC,α	α 0.20	EC	2.18	* 14.80	20.47	15.65
Eul44	Eul45	Eu146	Eul47	Eul48	Eu149	Eu150	Eu151	Eu152	Eu153	Eu154	Eu155	Eu156
10.2 s 1+	5.93 d 5/2+	4.59 d 4-	24.1 d 5/2+	54.5 d 5-	93.1 d 5/2+	30.9 y 5(-)	5/2+	13.537 y 3-	5/2+	8.593 y 3-	4.7611 y 5/2+	15.19 d 0+
EC	EC	EC	EC,α	EC,α	EC	EC *	47.8	ЕС,β-	52.2	ЕС,β- *	β-	β-
Sm143	Sm144	Sm145	Sm146	Sm147	Sm148	Sm149	Sm150	Sm151	Sm152	Sm153	Sm154	Sm155
3/2+	0+	340 a 7/2-	0+	1.00E+11 y 7/2-	0+	7/2-	0+	5/2-	0+	40.27 n 3/2+	0+	22.3 m 3/2-
EC *	3.1	EC	α	α 15.0	α 11.3	13.8	7.4	β-	26.7	β- *	22.7	β-
Pm142	Pm143	Pm144	Pm145	Pm146	Pm147	Pm148	Pm149	Pm150	Pm151	Pm152	Pm153	Pm154
40.5 s 1+	205 d 5/2+	303 d 5-	17.7 y 5/2+	5.53 y 3-	2.6234 y 7/2+	5.370 d	53.08 h 7/2+	2.08 h (1-)	28.40 h 5/2+	4.12 m 1+	5.4 m 5/2-	1.73 m (0,1)
EC *	EC	EC	EC,α	EC,β·	β-	β- *	β-	β-	β-	β- <sup>*</sup>	β-	β- *
Nd141	Nd142	Nd143	Nd144	Nd145	Nd146	Nd147	Nd148	Nd149	Nd150	Nd151	Nd152	Nd153
2.49 h 3/2+	0+	7/2-	2.29E+15 y 0+	7/2-	0+	10.98 d 5/2-	0+	1.728 h 5/2-	1.1E19 y 0+	12.44 m (3/2)+	11.4 m 0+	28.9 s (3/2-)
* EC	27.13	12.18	α 23.80	8.30	17.19	β-	5.76	β-	β- 5.04	β-	β-	β-

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Tb146	Tb147	Tb148	Tb149	Tb150	Tb151	Tb152	Tb153	Tb154	Tb155	Tb156	Tb157	Tb158
8 5	1.7 h	60 m	4.118 h	3.48 h	17.609 h	17.5 h	2.34 d	21.5 h	5.32 d	5.35 d	71 y	180 y
1+	(1/2+)	2-	1/2+	(2-)	1/2(+)	2-	5/2+	0	3/2+	3-	3/2+	3-
EC *	EC *	EC *	ΕC,α	EC,α *	EC,α <sup>#</sup>	EC,α <sup>*</sup>	EC	ЕС,β-	EC	EC,β-	EC	ЕС,β-
Gd145	Gd146	Gd147	Gd148	Gd149	Gd150	Gd151	Gd152	Gd153	Gd154	Gd155	Gd156	Gd157
1/2+	40.27 u 0+	7/2-	0+	7/2-	0+	7/2-	1.08E14 y 0+	3/2-	0+	3/2-	0+	3/2-
EC	EC	EC	α	EC,α	α	EC,α	α 0.20	EC	2.18	14.80	20.47	15.65
Eu144	Eul45	Eu146	Eul47	Eu148	Eu149	Eu150	Eu151	Eu152	Eul53	Eu154	Eu155	Eu156
10.2 s 1+	5.93 d 5/2+	4.59 d 4-	24.1 a 5/2+	54.5 d 5-	93.1 d 5/2+	30.9 y 5(-)	5/2+	13.537 y 3-	5/2+	8.593 y 3-	4.7011 y 5/2+	15.19 d 0+
EC	EC	EC	EC.a	EC.a	EC	EC *	47.8	±с.₿-	52.2	ЕС.β-	8-	B-
C 1 42	S-144	C 1 45	C	C 147	C 1 40	S 1 40	C 150	Con 151	6153	Sec. 152	C 154	C 155
8.83 m	Sm144	SII145 340 d	5m140 1.03E+8 y	Sm14/ 1.06E+11 v	5 <b>m148</b> 7E+15 v	Sm149 2E+15 v	Sm150	5m151 90 y	Sm152	5III 155 46.27 h	Sm154	22.3 m
					-	_						
3/2+	0+	7/2-	0+	7/2-	0+	7/2-	0+	5/2-	0+	3/2+	0+	3/2-
3/2+ EC	0+ 3.1	7/2- EC	0+ α	7/2- α 15.0	0+ α 11.3	7/2- 13.8	0+ 7.4	5/2- β-	0+ 26.7	<sup>3/2+</sup> * β-	0+ 22.7	3/2- β-
EC *	0+ 3.1 Pm143	7/2- EC Pm144	0+ α Pm145	7/2- α 15.0 Pm146	0+ α 11.3 Pml47	7/2- 13.8 Pm148	0+ 7.4 Pm149	5/2- β· Pm150	0+ 26.7 Pm151	<sup>3/2+</sup> * β- Pm152	0+ 22.7 Pm153	3/2- β· Pm154
EC + + + + + + + + + + + + +	0+ 3.1 Pm143 265 d 5/2+	7/2- EC Pm144 363 d 5-	0+ α Pm145 17.7 y 5/2+	α 15.0 Pm146 5.53 y 3-	0+ α 11.3 Pm147 2.6234 y 7/2+	7/2- 13.8 Pm148 5.370 d	0+ 7.4 Pm149 53.08 h 7/2+	5/2- β· Pm150 2.68 h (1-)	0+ 26.7 Pm151 28.40 h 5/2+	<sup>3/2+</sup> * β· Pm152 4.12 m 1+	0+ 22.7 Pm153 5.4 m 5/2-	3/2- β· Pm154 1.3 m
	0+ 3.1 Pm143 265 d 5/2+	7/2- EC Pm144 363 d 5-	0+ α Pm145 17.7 y 5/2+	7/2- a 15.0 Pm146 5.53 y 3-	0+ a 11.3 Pm147 2.6234 y 7/2+	7/2- 13.8 Pm148 5.370 d 1-	0+ 7.4 Pm149 53.08 h 7/2+	5/2- β· Pm150 2.68 h (1-)	0+ 26.7 Pm151 28.40 h 5/2+	$\beta^{-}$ * Pm152 4.12 m 1+ *	0+ 22.7 Pm153 5.4 m 5/2-	3/2- β- Pm154 15(3 m (0,1) *
<sup>3/2+</sup> EC Pml42 40.5 s 1+ EC	0+ 3.1 Pm143 265 d 5/2+ EC	7/2- EC Pm144 363 d 5- EC	0+ α Pm145 17.7 y 5/2+ EC,α	7/2- α 15.0 Pm146 5.53 y 3- EC,β-	0+ α 11.3 Pm147 2.6234 y 7/2+ β-	7/2- 13.8 Pm148 5.370 d 1- * β·	0+ 7.4 Pm149 53.08 h 7/2+ β-	5/2- β- Pm150 2.68 h (1-) β-	0+ 26.7 Pm151 28.40 h 5/2+ β-	<sup>3/2+</sup> * β· Pm152 4.12 m 1+ β·	0+ 22.7 Pm153 5.4 m 5/2- β-	3/2- β- <b>Pm154</b> 1.3 m (0,1
<sup>3/2+</sup> EC Pml42 40.5 s 1+ EC Ndl41 2.49 b	0+ 3.1 Pm143 265 d 5/2+ EC Nd142	7/2- EC Pm144 363 d 5- EC Nd143	0+ α Pm145 17.7 y 5/2+ EC,α Nd144 2 29E+15 x	7/2- α 15.0 Pm146 5.53 y 3- EC,β- Nd145	0+ α 11.3 Pm147 2.6234 y 7/2+ β- Nd146	7/2- 13.8 Pm148 5.370 d 1- * β. Nd147 10.98 d	0+ 7.4 Pm149 53.08 h 7/2+ β- Nd148	5/2- β· Pm150 2.68 h (1-) β- Nd149 1.728 h	0+ 26.7 Pm151 28.40 h 5/2+ β- Nd150 1 IE19 x	<sup>3/2+</sup> β· Pm152 4.12 m 1+ β· Nd151 12.44 m	0+ 22 7 Pm153 5.4 m 5/2- β- Nd152 11.4 m	3/2- β- <b>Pm154</b> 1.3 m (0,1. * β- Nd153 28.9.*
<sup>3/2+</sup> <u>EC</u> Pml42 40.5 s 1+ ± EC Ndl41 2.49 h 3/2+	0+ 3.1 Pm143 265 d 5/2+ EC Nd142 0+	7/2- EC Pm144 363 d 5- EC Nd143 7/2-	0+ α Pm145 17.7 y 5/2+ EC,α Nd144 2.29E+15 y 0+	7/2- α 15.0 Pml46 5.53 y 3- EC,β- Ndl45 7/2-	0+ α 11.3 Pml47 2.6234 y 7/2+ β- Ndl46 0+	7/2- 13.8 Pm148 5.370 d 1- ★ β- Nd147 10.98 d 5/2-	0+ 7.4 Pm149 53.08 h 7/2+ β- Nd148 0+	5/2- β- Pm150 2.68 h (1-) β- Nd149 1.728 h 5/2-	0+ 26.7 Pm151 28.40 h 5/2+ B- Nd150 1.1E19 y 0+	<sup>3/2+</sup> β- <b>Pm152</b> 4.12 m 1+ β- <b>Nd151</b> 12.44 m (3/2)+	0+ 22.7 Pm153 5.4 m 5/2- β- Nd152 11.4 m 0+	3/2- β- <b>Pm154</b> 1%3 m (0,1) * β- Nd153 28.9 s (3/2-)



Tb146	Tb147	Tb148	Tb149	Tb150	Tb151	Tb152	Tb153	Tb154	Tb155	Tb156	Tb157	Tb158
1+	(1/2+)	2-	1/2+	(2-)	1/2(+)	2-	5/2+	0	3/2+	3- -	3/2+	3
EC	EC	EC	ΕС,α	EC,α	EC,α <sup>°</sup>	EC,α <sup>°</sup>	EC	ЕС,β-	EC	ЕС,β-	EC	EC,β·
Gd145	Gd146	Gd147 38.06 h	Gd148	Gd149	Gd150	Gd151	Gd152	Gd153	Gd154	Gd155	Gd156	Gd157
1/2+	0+	7/2-	0+	7/2-	0+	7/2-	0+	3/2-	0+	3/2-	0+	3/2-
EC	EC	EC	α	EC,α	α	EC,α	α 0.20	EC	2.18	14.80	20.47	15.65
Eul44	Eul45	Eu146	Eul47	Eul48	Eul49	Eu150	Eu151	Eu152	Eul53	Eu154	Eu155	Eu156
10.2 s 1+	5.93 d 5/2+	4.59 d 4-	24.1 d 5/2+	54.5 d 5-	93.1 d 5/2+	30.9 y 5(-)	5/2+	13.537 y 3-	5/2+	8.593 y 3-	4.7011 y 5/2+	15.19 d 0+
EC	EC	EC	EC,α	ECα	EC	EC *	47 8	* ЕС.В-	52.2	ΈC,β-	в-	β-
Sm143	Sm144	Sm145	Sm146	Sm147	Sm148	Sm149	Sm150	Sm151	Sm152	Sm153	Sm154	Sm155
3/2+	0+	7/2-	0+	7/2-	0+	7/2-	0+	5/2-	0+	3/2+	0+	3/2-
EC T	3.1	EC	α	z 15.0	а 113	13.8		3-	26.7	β- <sup>#</sup>	22.7	<b>β</b> -
Pm142	Pm143	Pm144	Pm145	Pm146	2m147	Pm148	2m149	Pm150	Pm151	Pm152	Pm153	Pm154
40.5 s 1+	265 d 5/2+	363 d 5-	17.7 y 5/2+	5.53 y 3-	2.6234 y 7/2+	5.370 d 1-	53.08 h 7/2+	2.68 h (1-)	28.40 h 5/2+	4.12 m 1+	5.4 m 5/2-	1.73 m (0.1)
EC *	EC	EC	EC.α	EC.B-	β-	β- *	β-	в-	в-	β- *	β-	β-
Nd141	Nd142	Nd143	Nd144	Nd145	Nd146	Nd147	Nd148	Nd149	Nd150	Nd151	Nd152	Nd153
2.49 h	0+	70	2.29E+15 y	70	0.	10.98 d	AL	1.728 h	1.1E19 y	12.44 m	11.4 m	28.9 s
5/2+ *		112-	α	112-		012-		012-	β-	(3/2)+	0	(3/2-)
EC	94-14	12.18	23.80	8.30	17.19	0-	5.76	5	C 44	p-	p-	p-



Tb146	Tb147	Tb148	Tb149	Tb150	Tb151	Tb152	Tb153	Tb154	Tb155	Tb156	Tb157	Tb158
8 s 1+	1.7 h (1/2+)	60 m	4.118 h 1/2+	3.48 h (2-)	17.609 h 1/2(+)	17.5 h	2.34 d 5/2+	21.5 h	5.32 d 3/2+	5.35 d 3-	71 y 3/2+	180 y 3-
- <sup>-</sup> *	*	*	*	*	*	*		*		*		*
EC	EC	EC	EC,α	EC,α	EC,α	EC,α	EC	EC,β-	EC	EC,β-	EC	EC,B
Gd145 23.0 m	Gd146 48.27 d	Gd147 38.06 h	Gd148	Gd149 9.28 d	Gd150 1.79E6 y	Gd151 124 d	Gd152 1.08E14 y	Gd153 241.6 d	Gd154	Gd155	Gd156	Gd157
1/2+ *	0+	7/2-	0+	7/2-	0+	7/2-	0+	3/2-	0+	3/2- *	0+	3/2-
EC	EC	EC	α	EC,α	α	EC,α	0.20	EC	2.18	14.80	20.47	15.65
Eu144	Eul45	Eul46	Eul47	Eul48	Eul49	Eu150	Eu151	Eu152	Eu153	Eu154	Eu155	Eu156
10.2 s	5.93 d	4.59 d	24.1 d	54.5 d	93.1 d	36.9 y	<b>5 1 3 .</b>	13.537 y	<b>5</b> 48.	8.593 y	4.7611 y	15.19 d
1+	5/2+	4-	5/2+	9-	5/2+	<sup>5(-)</sup> *	5/2+	3- ÷	5/2+	3- *	5/2+	0+
EC	EC	EC	EC,α	ECα	EC	EC	47.8	EC.B-	52.2	ЕС,β-	β-	β-
Sm143 8.83 m	Sm144	Sm145	Sm146	Sm147	Sm148 7E+15 v	Sm149 2E+15 v	Sm150	Sm151	Sm152	Sm153 46.27 h	Sm154	Sm155 22.3 m
Sm143 8.83 m 3/2+	Sm144 0+	Sm145 340 d 7/2-	Sm146 1.03E+8 y 0+	Sml47 L06E+11 y 7/2-	Sm148 7E+15 y 0+	Sm149 2E+15 y 7/2-	Sm150 0+	Sm151 90 y 5/2-	Sm152 0+	Sm153 46.27 h 3/2+	Sm154 0+	Sm155 22.3 m 3/2-
Sm143 8.83 m 3/2+ ±	Sm144 0+ 3.1	Sm145 340 d 7/2- EC	Sm146 1.03E+8 y 0+ α	Sm147 L06E+11 y 7/2-	Sm148 7E+15 y 0+ x 113	Sm149 2E+15 y 7/2-	Sm150 0+	Sm151 90 y 5/2- 3-	Sm152 0+ 26.7	Sm153 46.27 h 3/2+ β-	Sm154 0+ 22.7	Sm155 22.3 m 3/2- 3 <sup>.</sup>
Sm143 <sup>8.83 m</sup> <sup>3/2+</sup> EC Pm142	Sm144 0+ 3.1 Pm143	Sm145 340 d 7/2- EC Pm144	Sm146 1.03E+8 y 0+ α Pm145	Sm147 L06E+11 y 7/2- 150 Pm146	Sm148 7E+15 y 0+ x 113 Pm147	Sm149 2E+15 y 7/2- 13 8 Pm148	Sm150 0+ Pm149	Sm151 90 y 5/2- 3- Pm150	Sm152 0+ 257 Pm151	Sm153 46.27 h <sup>3/2+</sup> β· Pm152	Sm154 0+ 22.7 Pm153	Sm155 22.3 m 3/2- β- Рm154
Sm143 <sup>8.83 m</sup> <sup>3/2+</sup> ± EC Pm142 40.5 s	Sm144 0+ 3.1 Pm143 265 d	Sm145 340 d 7/2- EC Pm144 363 d	Sm146 1.03E+8 y 0+ α Pm145 17.7 y	Sm147 L06E+11 y 7/2- L150 Pm146 5.53 y	Sm148 7E+15 y 0+ x 113 Pm147 2.6234 y	Sm149 2E+15 y 7/2- 13 8 Pm148 5.370 d	Sm150 0+ Pm149 53.08 h	Sm151 90 y 5/2- 3- Pm150 2.68 h	Sm152 0+ 25.7 Pm151 28.40 h	Sm153 46.27 h 3/2+ β Pm152 4.12 m	Sm154 0+ 227 Pm153 5.4 m	Sm155 22.3 m 3/2- 3- Pm154 1.73 m
Sm143     s.83 m     3/2+     ±     EC     Pm142     40.5 s     1+     ±     *	Sm144 0+ 3.1 Pm143 265 d 5/2+	Sm145 340 d 7/2- EC Pm144 363 d 5-	Sm146 1.03E+8 y 0+ α Pm145 17.7 y 5/2+	Sm147 L06E+11 y 7/2- 150 Pm146 5.53 y 3-	Sm148 7E+15 y 0+ 2 11 3 Pm147 2.6234 y 7/2+	Sm149 2E+15 y 7/2- 13 9 Pm148 5.370 d 1- *	Sm150 0+ 74 Pm149 53.08 h 7/2+	Sm151 90 y 5/2- 2- Pm150 2.68 h (1-)	Sm152 0+ 26.7 Pm151 28.40 h 5/2+	Sm153 46.27 h <sup>3/2+</sup> * β <sup>·</sup> Pm152 4.12 m 1 <sup>+</sup> *	Sm154 0+ 22.7 Pm153 5.4 m 5/2-	Sm155 22.3 m 3/2- B· Pm154 1.73 m (0,1)
	Sm144 0+ 3.1 Pm143 265 d 5/2+ EC	Sm145 340 d 7/2- EC Pm144 363 d 5- EC	Sm146 1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC.α	Sm147 L06E+11 y 7/2- L 150 Pm146 5.53 y 3- EC.β-	Sm148 7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β-	Sm149 2E+15 y 7/2- 13 8 Pm148 5.370 d 1- κ β-	Sm150 0+ 24 Pm149 53.08 h 7/2+ β-	Sm151 90 y 5/2- β- Pm150 2.68 h (1-) β-	Sm152 0+ 25.7 Pm151 28.40 h 5/2+ B-	Sm153 46.27 h 3/2+ β- Pm152 4.12 m 1+ β- β-	Sm154 0+ 22.7 Pm153 5.4 m 5/2- β-	Sm155 22.3 m 3/2- β- Pm154 1.73 m (0,1) *
Sm143 <sup>8.83 m</sup> <sup>3/2+</sup> EC Pm142 <sup>40.5 5</sup> <sup>1+</sup> EC Nd141 <sup>2.49 h</sup>	Sm144 0+ 3.1 Pm143 265 d 5/2+ EC Nd142	Sm145 340 d 7/2- EC Pm144 363 d 5- EC Nd143	Sml46 1.03E+8 y 0+ α Pml45 17.7 y 5/2+ EC.α Ndl44 2.20E+15 y	Sm147 L06E+11 y 7/2- L 150 Pm146 5.53 y 3- EC.β- Nd145	Sm148 7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β- Nd146	Sml49 2E+15 y 7/2- 13 8 Pml48 5.370 d 1- κ β- Ndl47	Sm150 0+ 24 Pm149 53.08 h 7/2+ β- Nd148	Sm151 90 y 5/2- β- Pm150 2.68 h (1-) β- Nd149	Sm152 0+ 25.7 Pm151 28.40 h 5/2+ B- Nd150	Sm153 46.27 h 3/2+ β· Pm152 4.12 m 1+ β· Nd151 12.44 m	Sm154 0+ 22.7 Pm153 5.4 m 5/2- β- Nd152	Sm155 22.3 m 3/2- β- Pm154 1.73 m (0,1) * β- Nd153 28.9 *
Sm143 <sup>3/2+</sup> EC Pm142 40.5 5 1+ EC Nd141 2.49 h 3/2+	Sm144 0+ 3.1 Pm143 265 d 5/2+ EC Nd142 0+	Sm145 340 d 7/2- EC Pm144 363 d 5- EC Nd143 7/2-	Sm146 1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC.α Nd144 2.29E+15 y 0+	Sm147 L00E+11 y 7/2- μ 150 Pm146 5.53 y 3- EC,β- Nd145 7/2-	Sm148 7E+15 y 0+ x 113 Pm147 2.6234 y 7/2+ β- Nd146 0+	Sml49 2E+15 y 7/2- 13 8 Pml48 5.370 d 1- π β- Ndl47 10.98 d 5/2-	Sm150 0+ 74 Pm149 53.08 h 7/2+ β- Nd148 0+	Sm151 90 y 5/2- 3- Pm150 2.68 h (1-) B- Nd149 1.728 h 5/2-	Sm152 0+ 25.7 Pm151 28.40 h 5/2+ B- Nd150 1.1E19 y 0+	Sm153 46.27 h 3/2+ β Pm152 4.12 m 1+ β Nd151 12.44 m (3/2)+	Sm154 0+ 22 7 Pm153 5.4 m 5/2- β- Nd152 11.4 m 0+	Sm155 22.3 m 3/2- β- Pm154 1.73 m (0,1) # β- Nd153 28.9 s (3/2-)



Tb146 8 s	Tb147 1.7 h	Tb148 60 m	Tb149 4.118 h	Tb150 3.48 h	Tb151 17.609 h	Tb152 17.5 h	Tb153 2.34 d	Tb154 21.5 h	Tb155 5.32 d	Tb156 5.35 d	Tb157 71 y	Tb158 180 y
EC 1+	(1/2+) EC *	2- EC *	±C,α +	(2-) EC,α *	<sup>1/2(+)</sup> * EC,α	2- ΕC,α *	5/2+ EC	υ EC,β-	3/2+ EC	3- ± ΕC,β-	3/2+ EC	3- έC,β-
Gd145 23.0 m	Gd146 48.27 d	Gd147 38.06 h	Gd148 74.6 y	Gd149 9.28 d	Gd150 1.79E6 y	Gd151 124 d	Gd152 1.08E14 y	Gd153 241.6 d	Gd154	Gd155	Gd156	Gd157
1/2+ *	0+	7/2-	0+	7/2-	0+	7/2-	0+ α	3/2-	0+	3/2- *	0+	3/2-
EC	EC	EC	α	ες,α	α	EC,α	0.20	EC	2.18	14.80	20.47	15.65
Eu144	Eul45	Eu146	Eul47	Eu148	Eu149	Eu150	Eu151	Eu152	Eu153	Eu154	Eu155	Eu156
10.2 s	5.93 d	4.59 d	24.1 d	54.5 d	93.1 d	36.9 y		13.537 y		8.593 y	4.7611 y	15.19 d
1+	5/2+	4-	5/2+	5-	5/2+	5(-)	5/2+	3-	5/2+	3-	5/2+	0+
EC	EC	EC	EC,α	EC a	EC	EC	47.8	EC.B-	52.2	ЕС,β-	β-	β-
Sm143	Sm144	Sm145	Sm146	Sm147	Sm148	Sm149	Sm150	Sm151	Sm152	Sm153	Sm154	Sm155
8.83 m		340 d	1.03E+8 v	L06E+11 v	7E+15 v	2E+15 v		90 v		46.27 h		22.3 m
8.83 m 3/2+	0+	340 d 7/2-	1.03E+8 y 0+	L06E+11 y 7/2-	7E+15 y 0+	2E+15 y 7/2-	0+	90 y 5/2-	0+	46.27 h 3/2+	0+	22.3 m 3/2-
8.83 m 3/2+ EC	0+ 31	340 d 7/2- EC	1.03E+8 y 0+ α	1.06E+11 y 7/2- 150	7E+15 y 0+ ¤	2E+15 y 7/2- 13 9	0+	90 y 5/2- R-	0+ 26.7	46.27 h 3/2+ β·	0+ 22.7	22.3 m 3/2- β-
8.83 m 3/2+ EC Pm142	0+ 31 Pm143	340 d 7/2- EC Pm144	1.03E+8 y 0+ α Pm145	L06E+11 y 7/2- <sup>k</sup> 150 Pm146	7E+15 y 0+ <sup>a</sup> 113 Pm147	2E+15 y 7/2-	0+ 74 Pm149	90 y 5/2- 3- Pm150	0+ 26.7 Pm151	46.27 h 3/2+ β- Pm152	0+ 22.7 Pm153	22.3 m 3/2- β· Pm154
	0+ 31 Pm143 265 d	340 d 7/2- EC Pm144 363 d	1.03E+8 y 0+ α Pml45 17.7 y	L06E+11 y 7/2- 150 Pm146 5.53 y	7E+15 y 0+ x 11.3 Pm147 2.6234 y	2E+15 y 7/2- 13 9 Pm148 5.370 d	0+ Pm149 53.08 h	90 y 5/2- Pm150 2.68 h	0+ 26.7 Pm151 28.40 h	46.27 h 3/2+ $\beta$ <b>Pm152</b> 4.12 m	0+ 22.7 Pm153 5.4 m	22.3 m 3/2- β- Pm154 1.73 m
	0+ 31 Pm143 265 d 5/2+	340 d 7/2- EC Pm144 363 d 5-	1.03E+8 y 0+ α Pm145 17.7 y 5/2+	L06E+11 y 7/2- 150 Pm146 5.53 y 3-	7E+15 y 0+ 2 11 3 Pm147 2.6234 y 7/2+	2E+15 y 7/2- 13 9 Pm148 5.370 d 1-	0+ 7.4 Pm149 53.08 h 7/2+	90 y 5/2- 3- Pm150 2.68 h (1-)	0+ 26.7 Pm151 28.40 h 5/2+	46.27 h 3/2+ $\beta$ · <b>Pm152</b> 4.12 m 1+	0+ 22.7 Pm153 5.4 m 5/2-	22.3 m 3/2- β- Pm154 1.73 m (0,1)
	0+ 31 Pm143 265 d 5/2+ EC	340 d 7/2- EC Pm144 363 d 5- EC	1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC,α	L06E+11 y 7/2- 150 Pm146 5.53 y 3- EC.β-	7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β-	2E+15 y 7/2- 13 9 Pm148 5.370 d 1- κ β-	0+ 7.4 Pm149 53.08 h 7/2+ β-	90 у 5/2- 3- Рт150 2.68 h (1-) β-	0+ 26.7 Pm151 28.40 h 5/2+ β-	46.27 h 3/2+ $\beta$ · <b>Pm152</b> 4.12 m 1+ $\beta$ ·	0+ 22.7 Pm153 5.4 m 5/2- β-	22.3 m 3/2- β- Pm154 1.73 m (0,1) * β-
8.83 m 3/2+ EC Pml42 40.5 s 1+ EC Ndl41	0+ 31 Pm143 265 d 5/2+ EC Nd142	340 d 7/2- EC Pm144 363 d 5- EC Nd143	1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC.α Nd144	L06E+11 y 7/2- 150 Pm146 5.53 y 3- EC.β- Nd145	7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β- Nd146	2E+15 y 7/2- 13 8 Pm148 5.370 d 1- β- Nd147	0+ Pm149 53.08 h 7/2+ β- Nd148	90 y 5/2- R- Pm150 2.68 h (1-) B- Nd149	0+ 25.7 Pm151 28.40 h 5/2+ B- Nd150	46.27 h 3/2+ β- Pm152 4.12 m 1+ β- Nd151	0+ 22 7 Pm153 5.4 m 5/2- β- Nd152	22.3 m 3/2- β- Pm154 1.73 m (0,1) ± β- Nd153
8.83 m 3/2+ EC Pm142 40.5 s 1+ ± EC Nd141 2.49 h	0+ 31 Pm143 265 d 5/2+ EC Nd142	340 d 7/2- EC Pm144 363 d 5- EC Nd143	1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC.α Nd144 2.29E+15 y	L06E+11 y 7/2- 1 ± 0 Pm146 5.53 y 3- EC.β- Nd145	7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β- Nd146	2E+15 y 7/2- 12 9 Pm148 5.370 d 1- π β- Nd147 10.98 d	0+ Pm149 53.08 h 7/2+ β- Nd148	90 y 5/2- Pm150 2.68 h (1-) B- Nd149 1.728 h	0+ 25.7 Pm151 28.40 h 5/2+ β- Nd150 1.1E19 y	46.27 h 3/2+ β· Pm152 4.12 m 1+ β· Nd151 12.44 m	0+ 22.7 Pm153 5.4 m 5/2- β- Nd152 11.4 m	22.3 m 3/2- β- Pm154 1.73 m (0,1) * β- Nd153 28.9 5
8.83 m 3/2+ EC Pm142 40.5 s 1+ ± EC Nd141 2.49 h 3/2+	0+ 31 Pm143 265 d 5/2+ EC Nd142 0+	340 d 7/2- EC Pm144 363 d 5- EC Nd143 7/2-	1.03E+8 y 0+ α Pm145 17.7 y 5/2+ EC.α Nd144 2.29E+15 y 0+	L06E+11 y 7/2- 1 5 0 Pm146 5.53 y 3- EC.β- Nd145 7/2-	7E+15 y 0+ α 113 Pm147 2.6234 y 7/2+ β- Nd146 0+	2E+15 y 7/2- 12 9 Pm148 5.370 d 1- π β- Nd147 10.98 d 5/2-	0+ Pm149 53.08 h 7/2+ β- Nd148 0+	90 y 5/2- R Pm150 2.68 h (1-) B- Nd149 1.728 h 5/2-	0+ 25.7 Pm151 28.40 h 5/2+ β- Nd150 1.1E19 y 0+	$\begin{array}{c} 46.27 \text{ h} \\ 3/2+}{}_{\#} \\ \beta \\ \hline \mathbf{Pm152} \\ 4.12 \text{ m} \\ 1+}{}_{\#} \\ \beta \\ \hline \mathbf{Nd151} \\ 12.44 \text{ m} \\ (3/2)+} \end{array}$	0+ 22.7 Pm153 5.4 m 5/2- β- Nd152 11.4 m 0+	22.3 m 3/2- β- Pm154 1.73 m (0,1) * β- Nd153 28.9 s (3/2-)

# r s p α

Tb146 8 s	Tb147 1.7 h	Tb148 60 m	Tb149 4.118 h	Tb150 3.48 h	Tb151 17.609 h	Tb152 17.5 h	Tb153 2.34 d	Tb154 21.5 h	Tb155 5.32 d	Tb156 5.35 d	Tb157 71 y	Tb158 180 y
EC I+	(1/2+) * EC	2- EC *	<sup>1/2+</sup> * EC,α	(2-) EC,α *	<sup>1/2(+)</sup> * EC,α	2- EC,α *	5/2+ EC	υ EC,β-	3/2+ EC	3- ± ΕC,β-	3/2+ EC	3- έC,β-
Gd145 23.0 m	Gd146 48.27 d	Gd147 38.06 h	Gd148 74.6 y	Gd149 9.28 d	Gd150 1.79E6 y	Gd151 124 d	Gd152 1.08E14 y	Gd153 241.6 d	Gd154	Gd155	Gd156	Gd157
1/2+ *	0+ EC	7/2- EC	0+ α	7/2- EC (1	0+ α	7/2- ΕC α	0+ α <sub>0.20</sub>	3/2- EC	0+ 2.18	<sup>3/2-</sup> ±	0+ 20.47	3/2-
Eu144	Eu145	Eu146	Eu147	Eu148	Eul49	Eu150	Eu151	Eu152	Eu153	Eu154	Eu155	Eu156
1+	5/2+	4- 4-	5/2+	5-	5/2+	5(-) *	5/2+	3- +	5/2+	3- *	5/2+	0+
EC	EC	EC	EC.α	ECa	EC	EC	47.8	EC.B-	52.2	ЕС,β-	B-	β-
Sm143 8.83 m	Sm144	Sm145 340 d	Sm146 1.03E+8 y	Sm147 L06E+11 y	Sm148 7E+15 y	Sm149 2E+15 y	Sm150	Sm151 90 y	Sm152	Sm153 46.27 h	Sm154	Sm155 22.3 m
3/2+ *	0+	7/2-	0+	7/2-	0+΄ α	7/2-	0+	5/2-	0+	3/2+ *	0+	3/2-
EC	31	EC	α	140	113	12.0		÷-	26.7	β-	202.47	3-
Pm142	Pm143	Pm144	Dm 145	D146	D 1/5							
	245.1	1 111 1 1	Pm145	Pm140	Pm147	Pm148	Pm149	Pm150	Pm151	Pm152	Pm153	Pm154
40.5 s 1+	265 d 5/2+	363 d	17.7 y	Pm140 5.53 y 3-	Pm14 / 2.6234 y 7/2+	Pm148 5.370 d	Pm149 53.08 h 7/2+	Pm150 2.68 h	Pm151 28.40 h 5/2+	Pm152 4.12 m 1+	Pm153 5.4 m 5/2-	Pm154 1.73 m (0 1)
40.5 s 1+ FC	265 d 5/2+	363 d 5-	РШ145 17.7 у 5/2+ ЕС а	Pm140 5.53 y 3- FCB-	Pm147 2.6234 y 7/2+ Br	Pm148 5.370 d 1- *	Pm149 53.08 h 7/2+ Br	Pm150 2.68 h (1-)	Pm151 28.40 h 5/2+	Pm152 4.12 m 1+ *	Pm153 5.4 m 5/2- 8-	Pm154 1.73 m (0,1) *
40.5 s 1+ EC	265 d 5/2+ EC	363 d 5- EC	Pm145 17.7 y 5/2+ EC.α	РШ140 5.53 у 3- ЕС, <u>β</u> -	Pm147 2.6234 y 7/2+ β-	Pm148 5.370 d 1- β-	Pm149 53.08 h 7/2+ β-	Рт150 2.68 h (1-) В-	Pm151 28.40 h 5/2+ β-	Pm152 4.12 m 1+ β-	Pm153 5.4 m 5/2- β-	Pm154 1.73 m (0,1) * β·
40.5 5 1+ EC Nd141 2.49 h	265 d 5/2+ EC Nd142	363 d 5- EC Nd143	PIII145 17.7 y 5/2+ EC.α Nd144 2.29E+15 x	Pm140 5.53 y 3- EC,β- Nd145	Pm14/ 2.6234 y 7/2+ β- Nd146	Pm148 5.370 d 1- β- Nd147 10.98 d	Pm149 53.08 h 7/2+ β- Nd148	Pm150 2.68 h (1-) B- Nd149 1.728 h	Pm151 28.40 h 5/2+ B- Nd150	Pm152 4.12 m 1+ β- Nd151 12.44 m	Pm153 5.4 m 5/2- β- Nd152 11.4 m	$\frac{\text{Pm154}}{1.73 \text{ m}} \\ (0,1) \\ * \\ \beta \cdot \\ \hline \text{Nd153} \\ 28.9.5 \\ \hline \end{array}$
40.5 s 1+ * EC Ndl41 2.49 h 3/2+	265 d 5/2+ EC Nd142 0+	363 d 5- EC Nd143 7/2-	PIII145 17.7 y 5/2+ EC.α Nd144 2.29E+15 y 0+	Pm140 5.53 y 3- EC.β- Nd145 7/2-	Pm147 2.6234 y 7/2+ β- Nd146 0+	Pm148 5.370 d 1- * β- Nd147 10.98 d 5/2-	Pm149 53.08 h 7/2+ β- Nd148 0+	Pm150 2.68 h (1-) B- Nd149 1.728 h 5/2-	Pm151 28.40 h 5/2+ B- Nd150 1.1E19 y 0+	Pm152 4.12 m 1+ β- Nd151 12.44 m (3/2)+	Pm153 5.4 m 5/2- β- Nd152 11.4 m 0+	Pm154 1.73 m (0,1) * β- Nd153 28.9 s (3/2-)

S.B. Jacobsen, G.J. Wasserburg, Earth Planet. Sci. Lett. 67, 137 (1984):  $^{143}$ Nd –  $^{147}$ Sm isochron in St-Severin meteorite : t = 4.55 ± 0.33 Gy



Fig 3 Sm-Nd evolution diagram for the St Severin chondrite

S.B. Jacobsen, G.J. Wasserburg, Earth Planet. Sci. Lett. 67, 137 (1984): <sup>146</sup>Sm in-situ decay in meteorites : <sup>146</sup>Sm present in Early-Solar system



Fig 6 <sup>142</sup>Nd/<sup>144</sup>Nd evolution diagram for the achondrites Moama and Angra dos Reis.



M. Boyet and R.W. Carlson, EPSL 250, 254 (2006)  $\epsilon(^{142}Nd)$ : deviation in parts per 10,000

#### Possible scenarios:

- 1. Earth condensed from nonchondritic material
- Early differentiation of Smrich material during planetary formation: Earth should therefore contain a complementary reservoir of low Sm/Nd ratio.

### Direct detection of <sup>146</sup>Sm by accelerator mass spectrometry: the interest

- 1. Possible determination of cross section of  ${}^{142}Nd(\alpha,\gamma){}^{146}Sm$ at low energy by direct counting for study of the inverse  $(\gamma,\alpha)$ p-process reaction
- Re-determination of <sup>146</sup>Sm half-life, important for Early-Solar System studies and planet formation
- 3. <sup>146</sup>Sm in nature:
  - cosmogenic isotope :  ${}^{147}Sm(n,2n)$  in meteorites ?
  - accretion from interstellar medium ?

## Laboratory production of <sup>146</sup>Sm

Eu144 10.2 s 1+	Eu145 5.93 d 5/2+	Eu146 4.59 d 4-	Eu147 ( <i>p</i> ,2 <i>n</i> )(ε)	Eu148 54.5 d 5-	Eu149 93.1 d 5/2+
EC	EC	EC	EC,α	EC,α	EC
Sm143	Sm144	Sm145	Sm146	$Sm_{1.06F+11.v}$	Sm148
3/2+	0+	7/2-	0+ (γ	(n) $7/2 (n)$	$2n^{9+}$
EC	3.1	EC	α	α 15.0	11.3
Pm142 40.5 s 1+	Pm143 265 d 5/2+	Pm144 363 d 5-	Pm145 17.7 y 5/2+	Pm146 5.53 y 3-	Pm147 2.6234 y 7/2+
EC *	EC	EC	EC,α	<b>EC</b> ,β-	β-
Nd141 2.49 h	Nd142	Nd143	Nd144 2.29E+15 y	Nd145	Nd146
3/2+	0+	7/2-	0+	7/2-	0+
EC *	27.13	12.18	α 23.80	8.30	17.19

AMS detection technique:

1. Use of ECR ion source and ATLAS to reach high energy

2. Use of Gas-Filled Magnet to separate <sup>146</sup>Sm and <sup>146</sup>Nd

Eu144 10.2 s 1+	Eu145 5.93 d 5/2+	Eu146 4.59 d 4-	Eu147 24.1 d 5/2+	Eu148 54.5 d 5-	Eu149 93.1 d 5/2+
EC	EC	EC	ΕС,α	ΕС,α	EC
Sm143 8.83 m 3/2+	Sm144 0+	Sm145 340 d 7/2-	Sm146 1.03E+8 y 0+	Sm147 1.06E+11 y 7/2-	Sm148 7E+15 y 0+
EC *	3.1	EC	α	α 15.0	α 11.3
Pm142 40.5 s 1+	Pm143 265 d 5/2+	Pm144 363 d 5-	Pm145 17.7 y 5/2+	Pm146 5.53 y 3-	Pm147 2.6234 y 7/2+
EC	EC	EC	EC,α	<b>EC,</b> β-	β-
Nd141 2.49 h	Nd142	Nd143	Nd144 2.29E+15 v	Nd145	Nd146
3/2+	0+	7/2-	0+	7/2-	0+

Identification  $\rightarrow$  high energy for discrimination by dE/dx













## **GFM Spectrograph**



Present status summary:

1. good separation and identification of <sup>146</sup>Sm by high-energy AMS

- 2. present sensitivity :  $^{146}$ Sm/Sm ~  $10^{-11}$
- 3. half-life re-determination in progress : need to measure <sup>146</sup>Sm/<sup>147</sup>Sm ratio in absolute terms.



$$t_{146} = \frac{A_{147}}{A_{146}} \times \frac{N_{146}}{N_{147}} \times t_{147}$$



Present status summary:

1. good separation and identification of <sup>146</sup>Sm by high-energy AMS

- 2. present sensitivity :  $^{146}$ Sm/Sm ~  $10^{-11}$
- 3. half-life re-determination in progress : need to measure <sup>146</sup>Sm/<sup>147</sup>Sm ratio in absolute terms.

Half-life (year)	Author
$5 \times 10^{7}$	D. C. Dunlavey and G. T. Seaborg, 1953
$7.4 \pm 1.5 \times 10^{7}$	M. Nurmia et al., 1964
$1.03 \pm 0.05 \times 10^{8}$	A. M. Friedman et al., 1966
$1.03 \pm 0.05 \times 10^{8}$	F. Meissner et al., 1987

#### <sup>146</sup>Sm samples

Sample	name	146/147 activity ratio (a)	estimated 146/147 atom ratio (a)	<sup>147</sup> Sm activation
(gamma	, n)			
	G-1	2.28x10 <sup>^</sup> -7	~2x10 <sup>^</sup> -10	50 MeV
	G-2	2.95x10 <sup>^</sup> -5	~3x10^-8	Tohoku U.
(n, 2n	1			
	N-1	5.18x10^-7	~5x10^-10	Iast neutrons Japan Material
	N-2	6.15x10 <sup>^</sup> -5	~6x10 <sup>^</sup> -8	Testing Reactor
(p,2n)	<u>sec</u>			
	P-1	2.50x10 <sup>^</sup> -7	~3x10^-10	21 MeV protons
	P-2	2.33x10 <sup>^</sup> -7	~2x10^-10	Osaka U.
	P-3	5.45x10 <sup>-4</sup>	~5x10^-7	
	P-4	5.12x10 <sup>4</sup> -4	~5x10^-7	
blank:	natural	Sm used for dilution		
	В	0.00	0.00	

(a): after dilution of activated material with  $^{147}\rm{Sm}$  and Sm purification. Samples were precipitated and ignited to  $\rm{Sm_2O_3}.$  Final masses of samples ~ 50 mg.



#### **SRIM 2006**







#### target chamber & Cu catcher assembly



S.B. Jacobsen, G.J. Wasserburg, Earth Planet. Sci. Lett. 67, 137 (1984): <sup>146</sup>Sm in-situ decay in meteorites : <sup>146</sup>Sm present in Early-Solar system



Fig 6 <sup>142</sup>Nd/<sup>144</sup>Nd evolution diagram for the achondrites Moama and Angra dos Reis.

#### E. Somorjai *et al.*, Astron. and Astroph. 333, 1112 (1998) $^{144}$ Sm $(\alpha, \gamma)^{148}$ Gd



Table 1. Experimental cross sections and S-factors for  $^{144}Sm(\alpha,\gamma)^{148}Gd$ 

$E_{\alpha}^{(a)}$ MeV	E <sup>eff. b)</sup> MeV	$\sigma$ $\mu$ barn	$\Delta \sigma$ $\mu$ barn	$S(\Delta S)$ $10^{26}$ MeV-barn
10.500	10.102	0.002	0.024	7 12 (2 02)
10.500	10.193	0.085	0.054	7.15 (2.92)
11.500	11.151	2.9	0.3	9.76 (1.01)
12.000	11.647	12.1	4.5	8.94 (3.32)
12.509	12.156	39.2	14.1	6.74 (2.42)
12.505	12.159	32.4	9.0	5.52 (1.53)
12.939	12.571	45.7	11.0	2.55 (0.61)
12.942	12.568	59.0	5.9	3.33 (0.33)
13.355	12.992	83.2	16.6	1.58 (0.31)

 $^{(a)}$  errors for  $E_{\alpha} \le 12$  MeV and for others are  $\pm 1.5$  keV and  $\pm 7$  keV (cyclotron), respectively

b) calculated from the target thicknesses

e.g.: <sup>142</sup>Nd ( $\alpha$ , $\gamma$ ) <sup>146</sup>Sm, measured by counting <sup>146</sup>Sm nuclei ?

Elution curve of Ln resin



#### <sup>58</sup>Ni (350 MeV)







#### Neutron Activated <sup>146</sup>Sm sample



#### Proton Activated <sup>146</sup>Sm sample



